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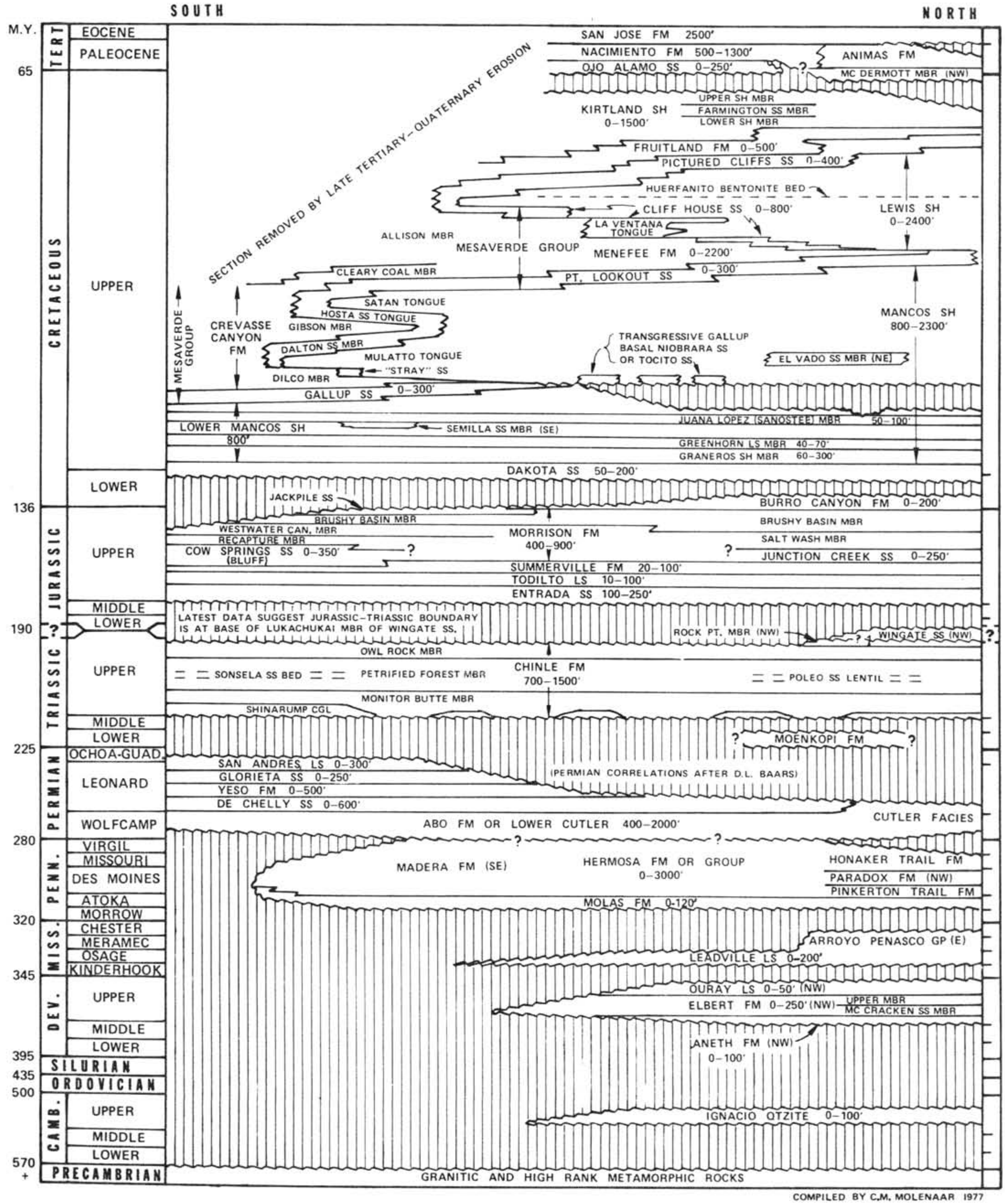

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INFLUENCES OF STRUCTURE ON JURASSIC DEPOSITIONAL PATTERNS AND URANIUM OCCURRENCES, NORTHWESTERN NEW MEXICO

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INTRODUCTION

A study of the stratigraphy of Middle and Upper Jurassic rocks in northwest New Mexico reveals depositional patterns that strongly reflect a pronounced change in tectonic activity at the close of San Rafael deposition. Deposition of the upper San Rafael Group in northwest New Mexico took place in a quiescent environment, and only broad regional movements were taking place. Depositional patterns and stratigraphy of the Morrison Formation, however, indicate that on the Four Corners platform and Red Rock bench a number of small structures were intermittently active during Morrison time. Strobell (1958, p. 73) recognized that "*. . . much of the structural configuration now visible is inherited from a tectonic pattern established in Pennsylvanian or even earlier time,*" in the Four Corners region, and pre-Dakota deformation has been documented in the southern San Juan Basin by Hilpert and Moench (1960) and Moench and Schlee (1967).

This report discusses the relationship of both regional and local structures to depositional patterns in the Jurassic rocks of northwest New Mexico. It further suggests that some of the smaller structures played a large role in the distribution of sediments favorable to uranium deposition. Such knowledge may provide an additional tool in the search for uranium in the San Juan Basin and surrounding areas.

STRUCTURAL SETTING

Structure of the Four Corners area is dominated by the Four Corners platform and the Red Rock bench which are intermediate in both structural and topographic elevation between the Defiance uplift and the San Juan Basin (fig. 1). The southern portion of the Four Corners platform is a 2- to 2.5-km thick sequence of sedimentary rocks dipping 2°-3° to the southeast. The platform is bounded on the east by the Hogback monocline, which dips 35°-60° to the southeast and has as much as 1.2 km of structural relief. The western boundaries are the Defiance monocline with easterly dips up to vertical and 1.2 km of structural relief, and the Mitten Rock monocline (Red Rock monocline of Kelley, 1957), with 5°-7° easterly dips and as much as 900 m of structural relief.

The Red Rock bench lies primarily in northeastern Arizona but extends into northwestern New Mexico. It is bounded on the east by the Mitten Rock monocline and on the north by the Rattlesnake monocline. Kelley and Clinton (1960, p. 68) placed the southern boundary at the Lukachukai monocline in agreement with Strobell (1958, p. 73), who considered the Red Rock bench a northern salient from the Defiance uplift.

Within the Four Corners platform and the adjacent Red Rock bench are a number of rather small, generally low-amplitude folds (fig. 1), many of which have oil and gas fields associated with them. Of particular interest in this study are the Tocito dome, Table Mesa anticline, Hogback anticline, Rattlesnake anticline, South Chimney Rock anticline and Beclabito dome. These features as well as the monoclines of this area have generally been considered to be of Laramide age (Kelley, 1955, Woodward, 1973).

STRATIGRAPHY

In northwestern New Mexico Jurassic rocks include part of the San Rafael Group of Late Jurassic age and the Morrison Formation of Late Jurassic age. The upper part of the San Rafael Group consists, in ascending order, of the Todilto Limestone, Summerville Formation and Bluff Sandstone. The Carmel Formation and Entrada Sandstone of the lower part of the San Rafael Group will be included in a later study.

In the Four Corners area Jurassic rocks are overlain by interbedded conglomerates and green mudstones of the Burro Canyon Formation of Early Cretaceous age. Farther south the Burro Canyon is missing from the section, probably owing to pre-Dakota erosion. Throughout most of northwestern New Mexico, Jurassic rocks are overlain by the Early(?) and Late Cretaceous Dakota Sandstone, which is composed of beds of sandstone, shale and coal.

Todilto Limestone

The Todilto Limestone has a uniform thickness of 3-4.5 m on the Four Corners platform and consists of an upper and lower part. On the Red Rock bench and along the Defiance uplift, the upper part is typically a 1.5- to 3-m-thick gray, thin-bedded silty to sandy limestone with a petroliferous odor; and the lower part is a grayish-red silty mudstone to siltstone as much as 1.5 m thick. Relief on the underlying Entrada Sandstone is as much as 1 m. The limestone pinches out in the vicinity of Oak Springs and is absent from there to the Colorado-New Mexico state line (fig. 2). Where the limestone is absent, the Entrada Sandstone is overlain by 1.5 m of grayish-red calcareous siltstone, which is in turn overlain by 0.5-1 m of white, medium-grained, crossbedded sandstone.

Summerville Formation

The Summerville Formation at the outcrop along the New Mexico-Arizona state line is divisible into upper and lower members. The lower member is a massive moderate-reddish-orange, very fine grained to fine-grained silty sandstone, containing horizontal wavy laminations and scattered gypsum crystals as much as 15 mm in length. The upper member consists of 1- to 2-m-thick beds of light-brown, very fine grained

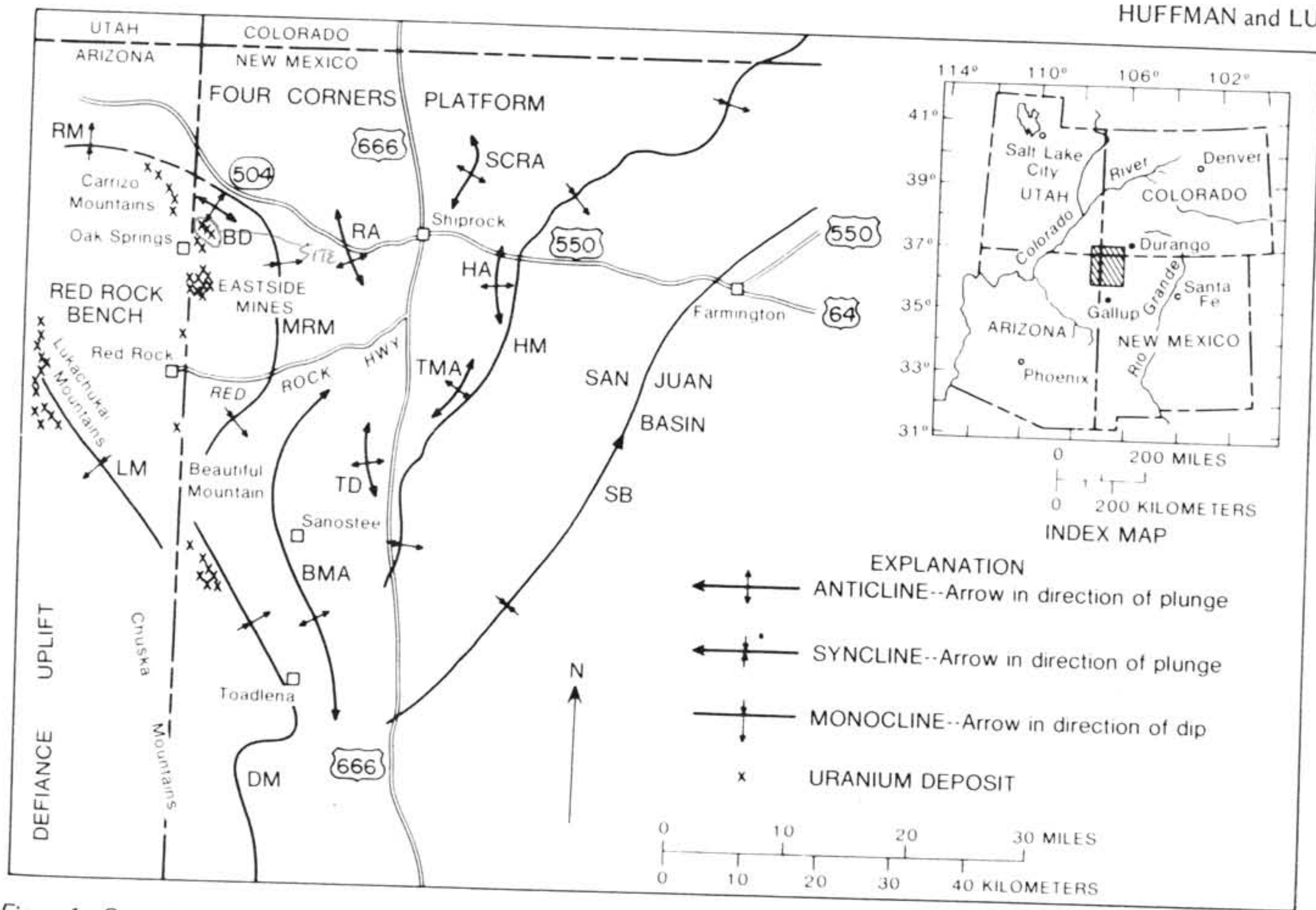


Figure 1. Generalized structure and location map, northwest New Mexico. Identified structures are: (SB) axis of San Juan Basin; (HM) Hogback monocline; (HA) Hogback anticline; (SCRA) South Chimney Rock anticline; (RA) Rattlesnake anticline; (MRM) Mitten Rock monocline; (RM) Rattlesnake monocline; (BD) Beclabito dome; (TMA) Table Mesa anticline; (TD) Tocito dome; (BMA) Beautiful Mountain anticline; (DM) Defiance monocline; and (LM) Lukachukai monocline.

to fine-grained, cross-laminated and horizontal, wavy laminated sandstone interbedded with 1- to 2-m-thick beds of moderate-reddish-brown, very fine grained, structureless sandstone to sandy siltstone.

The top of the upper member is coarser grained in an area that is roughly equivalent in size to that occupied by the lower sandstone member. Neither of these sandstone units can be recognized east of a line extending from the vicinity of Rattlesnake anticline to Tocito dome (fig. 3). To the north of the upper and lower sandstone members, a persistent 5- to 10-m-thick sandstone horizon occurs at about the middle of the upper member and can be traced along the New Mexico-Colorado border across the entire width of the map.

Bluff Sandstone

The Bluff Sandstone at the surface on the Red Rock bench is 10-20 m thick and is composed of moderate-reddish-orange to light-brown, fine- to medium-grained sandstone with horizontal wavy laminations; it includes several 0.3- to -.6-m beds of wedge cross-laminated sandstone. Traced eastward in the subsurface, the Bluff Sandstone grades laterally into a silty facies which forms a narrow (3.2-9.6 km) band trending northward through Tocito dome to Rattlesnake anticline and then eastward (fig. 4).

Morrison Formation

The Morrison Formation in northwest New Mexico is divided into four members, in ascending order: The Salt Wash, Recapture, Westwater Canyon and Brushy Basin.

Salt Wash Member

The Salt Wash in this area is highly variable both in thickness and lithology. In general the Salt Wash is a yellowish-gray to greenish-gray, very fine grained to medium-grained, calcareous sandstone interbedded with greenish-gray and reddish-brown claystone. The sandstone is commonly trough crossbedded with conglomeratic beds at the base of each trough. Parallel-laminated and massive or eolian crossbedded sandstone is often present in .2- to 2-m-thick beds. In the subsurface the Salt Wash becomes progressively finer grained to the east and south, so that clean sandstone beds are sparse on the eastern margin of the Four Corners platform and the Salt Wash is predominantly siltstone and mudstone.

Recapture Member

The Recapture Member in the northwestern part of the area is typically a pinkish-gray to pale-red, fine- to medium-grained calcareous subarkose interbedded with greenish-gray and reddish-brown claystone. Trough crossbedded sandstone and

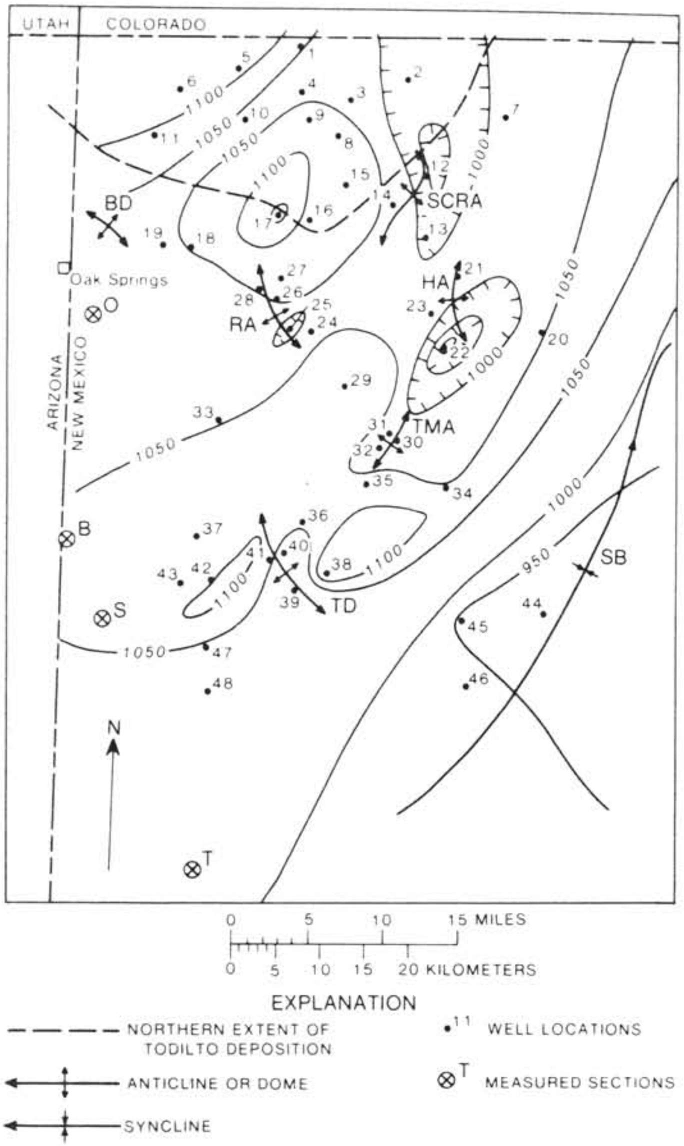


Figure 2. Isopach map of the Jurassic interval from the top of the Todilto Limestone to the base of the Dakota Sandstone—Four Corners platform and adjacent areas. Isopach interval 50 feet. North of Todilto deposition, top of Entrada used as lower limit. Locations of measured sections and drill holes used in compiling isopach maps are shown. Numbered wells, lettered measured sections, and identification numbers are keyed to Table 1. Identified structures are: (HA) Hogback anticline; (SCRA) South Chimney Rock anticline; (RA) Rattlesnake anticline; (BD) Beclabito dome; (TMA) Table Mesa anticline; (TD) Tocito dome.

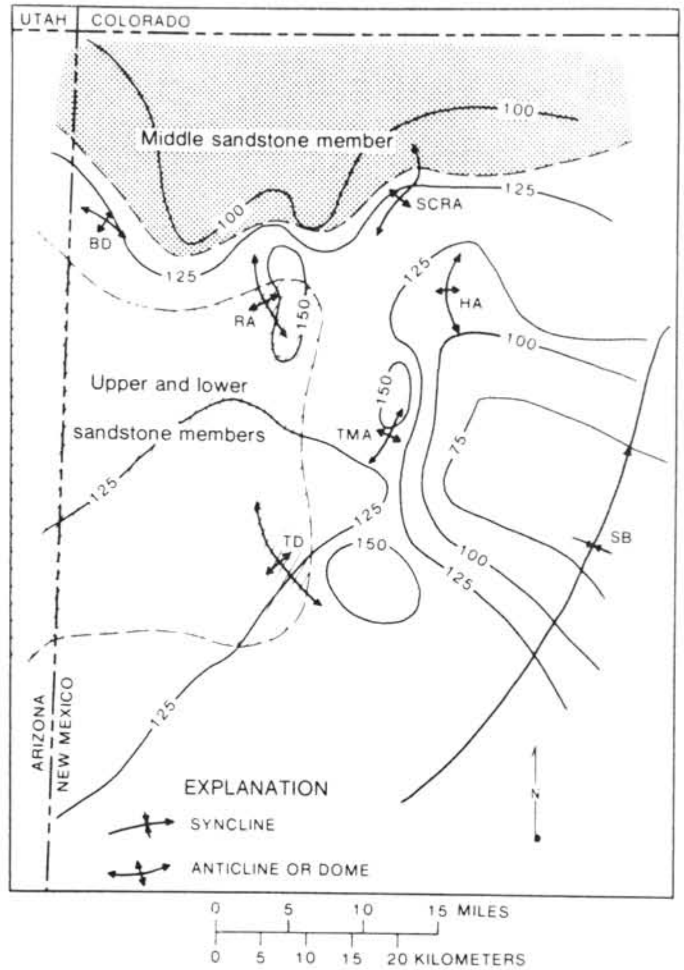


Figure 3. Isopach map of the Summerville Formation—Four Corners platform and adjacent areas. Isopach interval 25 feet. Identified structures are: (HA) Hogback anticline; (SCRA) South Chimney Rock anticline; (RA) Rattlesnake anticline; (BD) Beclabito dome; (TMA) Table Mesa anticline; (TD) Tocito dome.

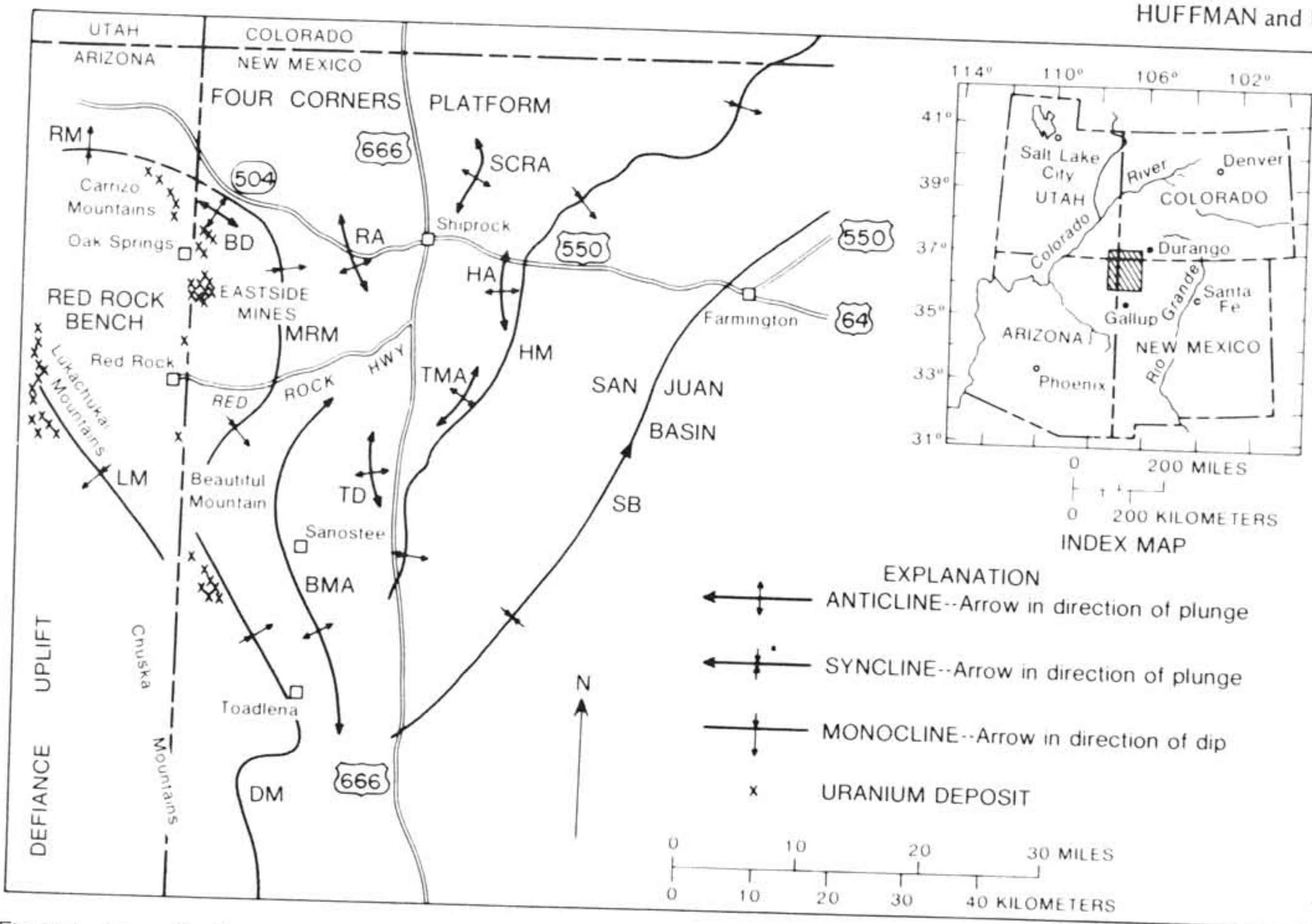
massive or eolian crossbedded, very friable sandstones are present. In the southwestern outcrop, the Recapture is roughly divisible into a lower fine- to medium-scale, trough crossbeded resistant sandstone and an upper claystone and friable, fine- to medium-grained sandstone with locally preserved crossbedding and conglomerate lenses.

Westwater Canyon Member

In the southwest part of the Four Corners platform, the Westwater Canyon Member is a moderate-reddish-orange, fine-grained, partly conglomeratic sandstone with minor interbedded dark-reddish-brown claystone. In the northwest the Westwater Canyon is a yellowish-gray, fine- to medium-grained, calcareous, arkosic, trough crossbedded sandstone with interbedded medium-gray to greenish-gray silty claystone. The Westwater Canyon is pale red to moderate reddish orange in a 22-km-wide band from Beautiful Mountain northward to the vicinity of Oak Springs (fig. 1). The unusual color change is associated with the oxidation of pyrite to hematite. A similar color change is also apparent in sandstones of the upper part of the Recapture and lower part of the Brushy Basin for several kilometers to the north and south of the Red Rock highway.

Brushy Basin Member

The Brushy Basin Member is dominantly grayish-green to pale-green mudstone and siltstone with interbedded grayish-green chert, limestone and quartzite. In the northwestern part of the area, it commonly includes lenses of yellowish-gray, medium-grained, crossbeded, calcareous, arkosic sandstone, 7-9 m thick, which are indistinguishable from sandstone in the Westwater Canyon Member. An undetermined amount of



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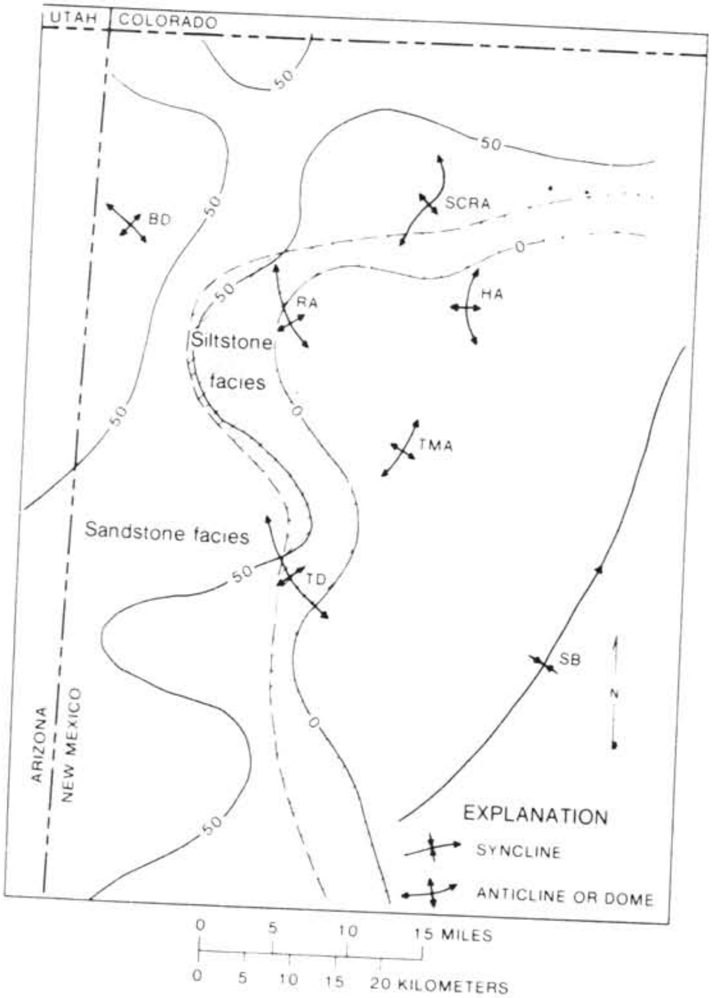

Figure 4. Isopach map of the Bluff Sandstone--Four Corners platform and adjacent areas. Isopach interval 50 feet. Silty facies enclosed between dashed line and zero contour. Identified structures are: (HA) Hogback anticline; (SCRA) South Chimney Rock anticline; (RA) Rattlesnake anticline; (BD) Beclabito dome; (TMA) Table Mesa anticline; (TD) Tocito dome.

Brushy Basin was removed by pre-Dakota erosion in the central and southern portions of the area.

DEPOSITIONAL HISTORY

An analysis of subsurface data from well logs has provided information on the depositional history of the Middle and Upper Jurassic rocks in northwestern New Mexico and suggests structural influence on many of the depositional patterns. The locations of the measured sections, well, and types of logs used in this analysis are listed in Table 1.

An isopach map of the interval from the top of the Todilto Limestone to the base of the Dakota Sandstone (fig. 2) reveals a general association of relatively thin areas with many of the small anticlines and domes previously mentioned. These two surfaces were chosen as limits of this study because they are particularly good "picks" on the well logs, and both surfaces are considered to have been nearly planar features at the scale of this figure. Beyond the limit of Todilto deposition to the north, the top of the Entrada Sandstone was used as the lower boundary. Although the correlation of thin areas with present

Table 1. Locations of wells, measured sections and types of logs used in producing Figures 2-5. Numbers and letters keyed to locations on Figure 2.

Well No.	Well	Company	Location sec.	T.	R.	Log elec.	gamma	lith.
1	#1-N Navajo	The Texas Co.	17	32	18	x	x	
2	#1-B Navajo	Texas Pacific	28	32	17	x		x
3	Navajo AJ#1	Texaco	35	32	18	x	x	x
4	1-32 Navajo	Compass	32	32	18	x	x	x
5	#1-21 Navajo	Conoco	21	32	19	x	x	
6	Navajo 590#1	Tenneco	36	32	20	x	x	
7	#1-6 Navajo Ute	Standard Oil of Texas	3	31	16	x	x	x
8	Navajo Tract 24#1	Humble	15	31	18	x		
9	#1-C Navajo	Humble	8	31	18	x	x	x
10	#1-B Navajo	Pan American	10	31	19	x	x	x
11	#1-E Navajo	British American	15	31	20	x	x	
12	Navajo #1	Three States Nat. Gas	27	31	17	x		x
13	Navajo Tribal 130 #15-1	Standard Oil of Texas	15	30	17	x		
14	Navajo #1	Phillips Petro.	5	30	17	x	x	
15	Navajo Tribal #1-21	Standard Oil of Texas	35	31	18	x	x	
16	Navajo Tribal AP-1X	Texaco	8	30	18	x		x
17	San Juan #1	Sinclair	12	30	19	x	x	
18	#1 Navajo Tract 10	Amerada	24	30	20	x	x	x
19	#1-11 Navajo	Pure Oil/Ohio Oil	23	30	20	x	x	x
20	1-2 Navajo	Pure/Sun/Humble	18	29	15	x	x	
21	2-K Navajo	Humble	31	30	16	x		
22	#1 Navajo	M. M. Garrett	25	29	17	x		
23	#1 Navajo F. Hamrah	San Juan Drilling Co.	11	29	17	x	x	
24	#1-21 Shell Navajo	Kern Co. Land Co.	21	29	18	x		
25	Kern Co. Rattlesnake #1	Conoco	19	29	18	x		
26	Rattlesnake #142	Conoco	12	29	19	x	x	
27	#135 Navajo	Conoco	1	29	19	x		x
28	#136 Rattlesnake	Conoco	2	29	19	x	x	
29	Navajo 1-12	Champlin	13	28	18	x	x	x
30	#3-18 Table Mesa	Conoco	3	27	17	x	x	
31	Table Mesa #28	Conoco	33	28	17	x		
32	#24 Table Mesa	Conoco	4	27	17	x		
33	Navajo #1-32	Amerada	27	28	19	x	x	x
34	Chaco Wash Navajo #1	Conoco	19	27	16	x		
35	Navajo Tract 4#1	Amerada	20	27	17		x	
36	Navajo Tribal 141#1	Sinclair	34	27	18	x		
37	Navajo 381#1	Amerada	5	26	19	x	x	
38	San Juan #1	Sinclair	23	26	18	x	x	x
39	Navajo AL#1	Texaco	28	26	18	x	x	
40	Navajo Tribal 'p'#3	Pan American	8	26	18	x		
41	Tocito Unit #1	Stanolind/Conoco	17	26	18	x		
42	Navajo Tribal 52 #1-21	Apache	21	26	19	x	x	x
43	#1-D Navajo	Humble	30	26	19	x		x
44	#1-27 Navajo	Pure Oil	32	26	15	x	x	
45	# Gulf Navajo	Pan American	4	25	16	x	x	x
46	#1 Navajo	Gulf	28	25	16	x	x	
47	Navajo Humble #1	Champlin	16	25	19	x	x	x
48	Navajo Tribe AO #1	Texaco	33	25	19	x	x	x

Section	Measured by	Location	sec.	T.	R.	Reference
O	L. C. Craig and J. D. Strobell	Oak Spring	13	29	21	Craig and others, 1959
B	J. D. Strobell	Beautiful Mtn.	11	26	21	Unpublished data
S	L. C. Craig, V. L. Freeman and G. W. Weir	Sanostee Wash	5	25	20	Craig and others, 1959
T	L. C. Craig and V. L. Freeman	Toadlena	32	23	19	Craig and others, 1959

structures is not precisely one to one, it at least intimates that some degree of tectonic activity occurred in the vicinity of most of the small structures at some time between deposition of the Todilto and of the Dakota.

The patterns of sediment distribution of the Todilto, Summerville and Bluff formations show many similarities; their patterns are quite different from those of the Morrison Formation. The Todilto Limestone was deposited in about 14,000 years (Anderson and Kirkland, 1960, p. 49) either in a large bay with a restricted opening to a sea in Utah (McKee and others, 1956; Harshbarger and others, 1957) or in a large saline lake (Anderson and Kirkland, 1960; O'Sullivan and Craig, 1973). At the end of the Todilto deposition, the area from the Four Corners to the east along the state line was a positive feature and the region to the south was structureless and depressed. The distribution of higher energy sediments within the Summerville Formation on the Four Corners platform indicates that the area to the west was relatively high at both the beginning and end of Summerville deposition (fig. 3), while the area to the east and southeast remained a basin. The higher energy sand in the middle of the upper member along the northern margin of the map also suggests a positive area to the north during mid to late Summerville time. Distribution of sediments within the Bluff indicates higher energy environments and sediment sources to the north and west of the Four Corners platform (fig. 4) throughout Bluff deposition.

The southern and eastern limits of the Bluff (fig. 4) very nearly coincide with the southern and eastern limits of the higher energy Summerville sediments (fig. 3), as well as with the north and northwestern edge of Todilto deposition (fig. 2). Such similarities suggest that throughout the latter stages of San Rafael deposition positive areas existed to the north and west of the Four Corners platform, while a basin was present to the east. The margins of the basin roughly paralleled the present margins of the San Juan Basin; and, although there were slight relative movements between these elements, the period was generally quiescent.

Deposition of the Morrison Formation in northwest New Mexico involved a fundamental change in pattern from deposition of the San Rafael Group. This change in pattern is from a rather subdued basin margin showing only slight indications of regional structure control to a high-energy, highly variable environment indicative of both local and regional structural influence. The lithology, bedding structures, fossils and regional stratigraphy indicate that the Morrison is a stream and flood plain deposit having minor lacustrine and eolian components. In northwest New Mexico the Morrison consists dominantly of fluvial deposits laid down on large alluvial plains or fans (Craig and others, 1955). Linear thickness trends on each isopach map of the Morrison (fig. 5) are interpreted as indicating the main loci of fluvial deposition. The inferred transport direction indicated by the isopachs agrees with earlier generalized interpretations of Morrison deposition (Craig and others, 1955), as well as with detailed studies of the Morrison in the Carrizo Mountains area (Stokes and others, 1953; Stokes, 1954; Lowell, 1955; Masters, 1955). Sandstone/shale ratios show consistently higher values for the thick areas and lower values for the thin areas. In general these axes are commonly diverted around or bifurcated by the thin areas associated with small structures which suggest topographic highs and probable intermittent movement on these structures during deposition. An axis crossing a structure would indicate that part or all of that structure was not active at the time of deposition.

The Salt Wash Member generally thins to the south and east in the subsurface. Major axes enter the area from the west and northwest and are diverted or bifurcated by all or parts of the present anticlinal structures (fig. 5a). In general the Recapture Member thins to the east and north, with the major axes entering the area from the southwest (fig. 5b). During deposition of the Recapture, topographic highs apparently existed in the vicinity of the Beclabito dome, between Rattlesnake and South Chimney Rock anticlines, and at Tocito dome and Table Mesa anticline. During Westwater Canyon deposition the main axis entered the area from the south and bifurcated around the northern end of Tocito dome; the resultant axes were deflected or bifurcated by all of the anticlinal structures with the possible exception of the Rattlesnake anticline (fig. 5c). The general thinning of the Brushy Basin Member to the south may be due in part to depositional patterns and in part to pre-Dakota erosion. Figure 5d indicates that the primary axes into northwestern New Mexico during Brushy Basin deposition were from the northwest. The area from Beclabito dome through Rattlesnake anticline to the Hogback anticline was apparently a positive feature as was the area from Tocito dome to Table Mesa anticline.

URANIUM DEPOSITS

On the Four Corners platform, Red Rock bench and adjacent areas, uranium has been mined from the Salt Wash and Recapture members of the Morrison Formation. Production from the Salt Wash has been concentrated around the Carrizo Mountains and in the Lukachukai Mountains, although none of the mines are currently active. A small amount of uranium has been mined from the Recapture in the Sanostee area, where one mine, the Enos Johnson, is still in production. Mineralization has also been reported from the Todilto Limestone in the Sanostee area (Blagbrough and others, 1959).

Salt Wash deposits in the vicinity of the Carrizo and Lukachukai mountains are often located in areas where the paleostream channel systems are curving or are losing energy for some other reason (Stokes, 1954). This loss of energy allowed the organic debris being carried by the streams to accumulate and later to act as a reductant for the deposition of uranium. The Salt Wash deposits at the Eastside mines (figs. 1 and 5a) are located where the paleostream directions change from southeast to east (Stokes and others, 1953). The ore in the Eastside mines is primarily metatyuyamunite, having an average U/V ratio of 1:11 (Hilpert, 1969), and is found mainly in finely laminated or massive sandstone associated with organic debris.

Subsurface gamma-ray anomalies within the Salt Wash on the Four Corners platform occur away from the main axes, often on the flanks of paleotopographic highs and near major bends of the axes. This is consistent with the observed depositional patterns in the vicinity of known deposits on the Red Rock bench and leads to speculation that the axes of maximum thickness, shown on Figure 5, represent the persistent location of paleostream channel systems. The high sandstone/shale ratios, thus higher energy environments, consistently occur along these axes, strengthening the theory that they are the locations of paleostream channel systems.

Uranium deposits in the Recapture occur in the upper part of the member and are associated with clay lenses in a zone of bleached sand. Two types of ore, one black and the other red, occur in the Enos Johnson mine. The black ore consists primarily of coffinite, but some uranium is also intimately admixed in pyrite grains. The red ore contains uranium dispersed in hematite and other ferric hydroxides that coat sand grains. Microprobe analysis failed to identify any discrete uranium phases in the red ore (R. A. Brooks, written commun., 1977). Both types of ore are closely associated with clay seams and galls. Uranium and vanadium concentrations show a ratio of

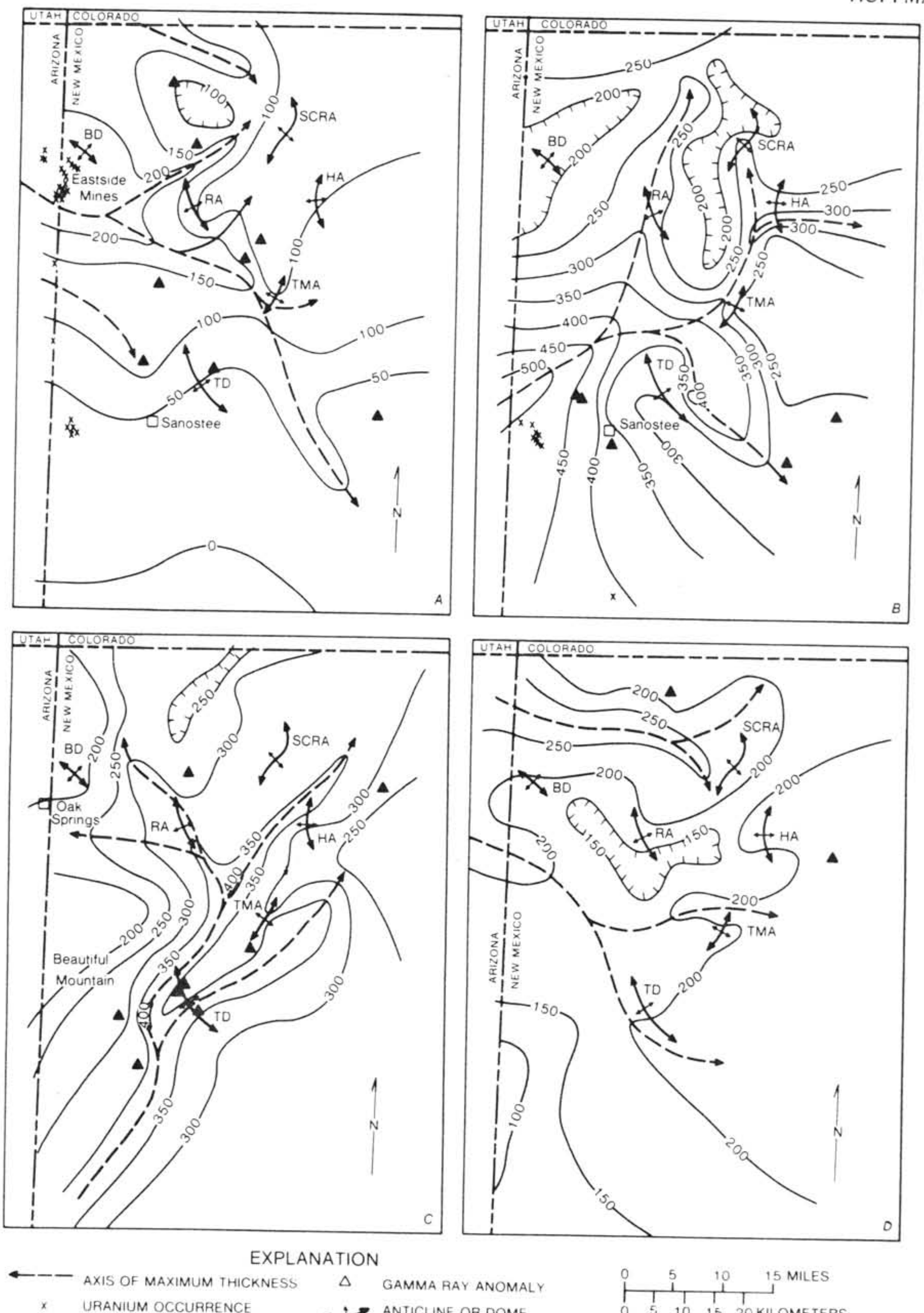

Figure 5. Isopach maps of the (A) Salt Wash, (B) Recapture, (C) Westwater Canyon and (D) Brushy Basin members of the Morrison Formation–Four Corners platform and adjacent areas. Axes of maximum thickness shown by dashed lines. Isopach interval 50 feet. Identified structures are: (HA) Hogback anticline; (SCRA) South Chimney Rock anticline; (RA) Rattlesnake anticline; (SCRA) South Chimney Rock anticline; (RA) Rattlesnake anticline; (BD) Beclabito dome; (TMA) Table Mesa anticline; (TD) Tocito dome.

approximately 1:1. The only gamma-ray anomalies in the Recapture occur down the regional dip from the Sanostee deposits (fig. 5b). These Recapture deposits are quite different from the Salt Wash deposits on the Red Rock bench both in geology and in location and do not necessarily bear the same relationship to the depositional patterns as do the Salt Wash deposits.

Gamma-ray anomalies in the Westwater Canyon Member (fig. 5c) occur along the margins of the thickest portions of the lobes, commonly at bends in the axes or around inferred paleotopographic highs. If these anomalies are in fact caused by deposits of uranium, their location could be accounted for by the accumulation of organic debris in the lower energy environments or by variations in the sandstone/shale ratios along the margins of paleostream channel systems.

Only two gamma-ray anomalies were found in the Brushy Basin (fig. 5d), both occurring in silty sandstones.

CONCLUSIONS

Depositional patterns in the Middle and Upper Jurassic rocks of northwestern New Mexico show that this area was affected by an increase in tectonic activity at the same time that orogenic activity to the south and west produced the clastic fans of the Morrison Formation. The upper part of the San Rafael Group was deposited during a period of relative quiescence, with only broad regional movements affecting sedimentation. During Morrison deposition the broad features such as the previously discussed basin were masked completely by the rapid influx of sediments; at the same time a number of smaller structures were quite active, exerting a pronounced influence on sedimentation.

Uranium occurrences in the Salt Wash on the Red Rock bench and gamma-ray anomalies in the Salt Wash and Westwater Canyon in the subsurface of the Four Corners plateau appear to be related to the linear-thickness trends of the isopach maps. Extrapolation from outcrop data leads to the speculation that these linear-thickness trends represent persistent paleostream channel systems and that the locations of these systems were controlled to some extent by the small anticlinal structures that were active at various times during the Late Jurassic and reactivated during the Laramide orogeny.

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